North Pacific Acoustic Laboratory (NPAL) – Measurement and Modeling of Long Range Ocean Acoustics

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LONG-TERM GOALS

The long-term goal of this research is to understand deep-water propagation, with particular emphasis placed on the passive quiet target detection problem. Focus is on the spatial/temporal structure of acoustic paths for moving sources and moving receivers. Propagation paths are separated into two classes: bottom interacting and refracted/surface-reflected (non-bottom interacting). This research seeks to understand the impact that mid-ocean variability (internal waves, mixed layer variability) and seafloor scattering have on the detection problem.

OBJECTIVES

The objectives of the FY10 effort were to process FY09 data and conduct the FY10 experiment to measure acoustic signals for a set of propagation paths. The FY09 sources included an axial moored source, a ship towed shallow source and a ship suspended axial source. Specific scientific objectives are: to develop an understanding of the sensitivity of the structure of the convergence zone to ocean meso-scale variability; to investigate the structure and spatial variability of bottom bounce acoustic paths; to develop an understanding of the sound field behind a ridge or seamount.

APPROACH

Work this year was focused on three areas: , conducting the PhilSea10 experiment, PhilSea09 data analysis, and numerical model development. The processing of data from the FY09 test was conducted in two ways, for the two array configuration data-sets we have. The FORA data (towed line array) was processing as Bearing Time Records (FFT then conventional beamforming) for the selection of interesting times. This approach permits accurate measure of signal arrival structure and transmission loss. The DVLA data was time-aligned, and then narrowband processed for Matched Field Processing. For the PhilSea10 experiment, the goal was to conduct a series of transmissions (narrowband and broadband) to study bottom bounce propagation, signal stationarity for fixed-fixed systems (with slight drift) and to examine the affect of bathymetric scattering from a ridge on the propagating signal. To facilitate model-data comparisons for complex geometries (including out-of-plane scattering from a rough seafloor), a Parabolic Equation was coded in C (called CRAM_Nx2D).

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WORK COMPLETED

PhilSea10 Mobile Operations Experiment

In May of 2010 Dr. Peter Worcester (SIO) deployed a fully spanning vertical line array in the central Philippine Sea. In addition to receiving from Worcester's tomographic source, the array was scheduled to record in specific windows assigned to the use of a mobile ship suspended source. This portion of the experiment was conducted from July 4-July 19, 2010, by Kevin Heaney, Richard Campbell, under the direction of Chief Scientist Prof. Arthur Baggeroer (MIT). Source receiver geometries included spanning a convergence zone (CZ), long-range propagation (2-3 CZ's out to 200 km), scattering from a seafloor ridge and near source bottom bounce propagation. The summary of geometries for the R/V Melville are shown in Figure 1 below. A combination of narrowband tones, broadband LFM and band limited white-noise were transmitted. The source was towed in a Star-of-David pattern spanning ranges near ½ CZ from the receiver. A series of stationary transmissions (cyan stars) were made at 17, 18, 19 nmi as well as a 2 km CPA. Two long tows (red line/blue line) were made north-east of the array towards the Worcester source T1,

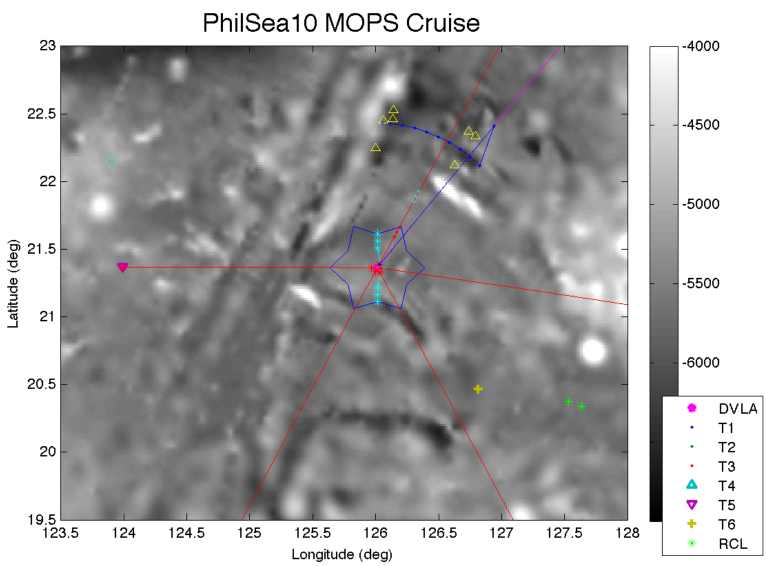

Figure 1. PhilSea 10 Mobile Operations Test Geometries.

CRAM_Nx2D Development

The CRAM code is based entirely on NSPE2.0 (a descendant of RAM developed by Collins[1]) coded from scratch in Ansi-standard C. The code handles all environmental (via netcdf) and source/receiver geometry input and permits use of OpenMP to optimize memory and multi-processor threading. Multiple sources to receivers of all kinds can be run in the execution of a single command. The CRAM interface has permitted the efficient computation of the field for a range of problems including TL from multiple sources (T1-T5 in PhilSea10, see Fig 2 below), R/V Melville CPA passing (not radial) in PhilSea09 (see Fig 4 below), out-of-plane bottom roughness computations and basin scale propagation modeling the Perth-Bermuda Experiment (see Fig 3 below) and Matched Field Processor replica generation for PhilSea09 (see Fig 5 below).

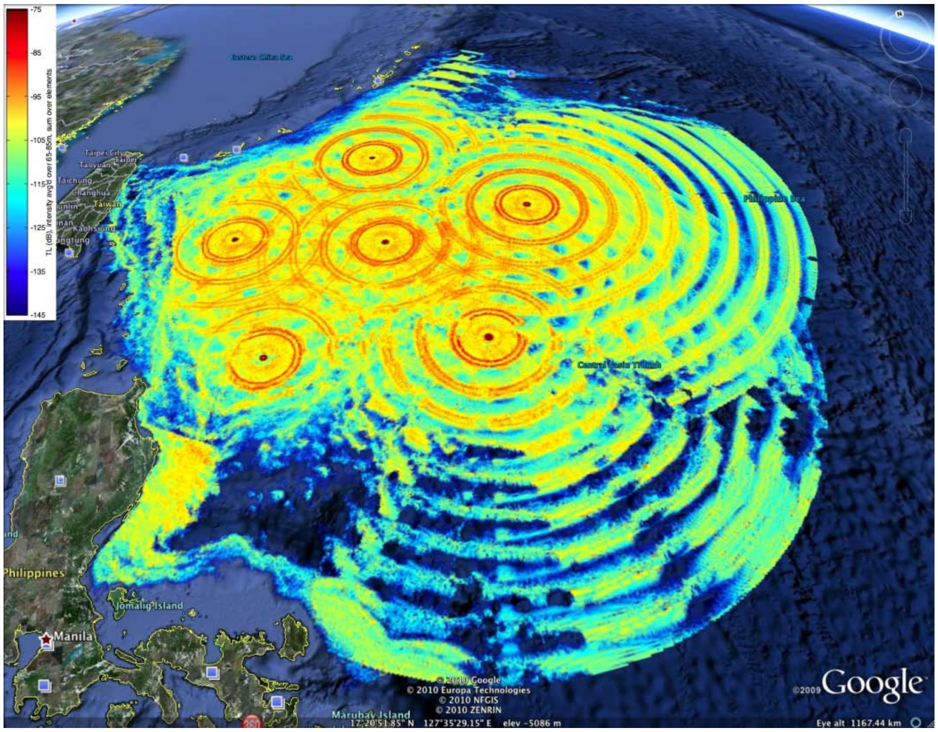

Figure 2. PhilSea 10 Transmission Loss from all 6 Worcester mooring locations to a shallow receiver.

The Nx2D PE model was extended to the basin scale problem, as demonstrated in the Perth-Bermuda simulation below. The multiple propagation paths to Bermuda modeled by Heaney, et. al.[2], can be seen in the right figure, although without horizontal refraction, they converge several hundred km away from the recording site at Bermuda.

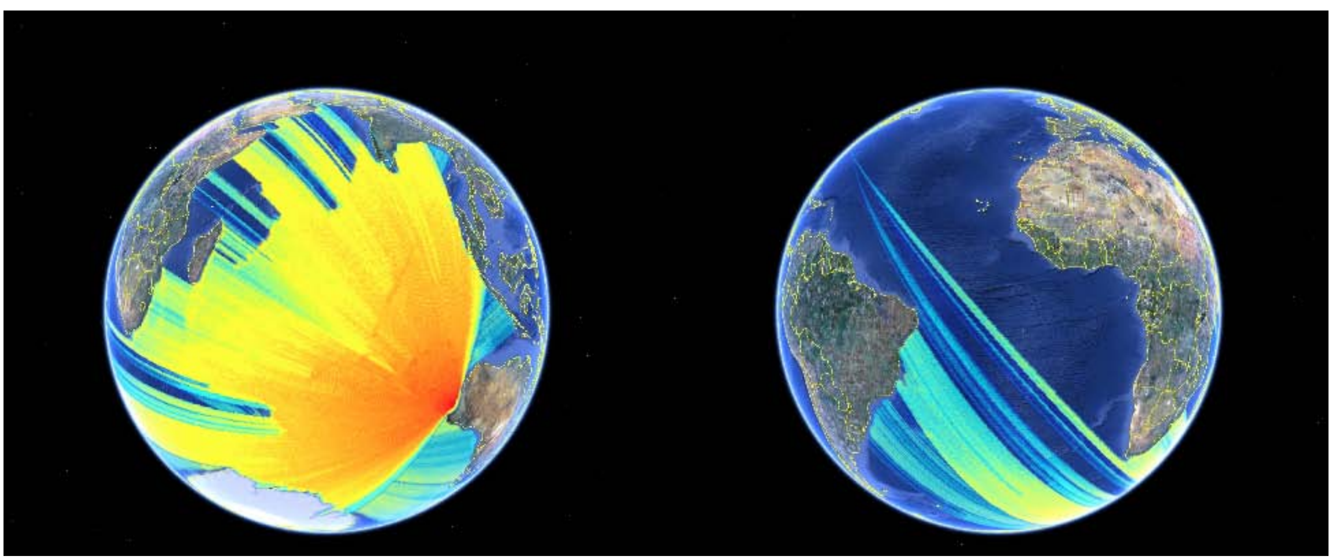

Figure 3. Perth-Bermuda model results using the CRAM_Nx2D code. This model contains bathymetric interaction, spatially variable sound speed profiles but not refraction.

RESULTS

A few selected results from processing of the PhilSea09 data are now presented. First, from the FORA array data, a narrowband BTR (Bearing Time Record) is shown in Fig 4 for when the R/V Kilo Moana (which was towing the FORA) closed on the source suspended from the stationary R/V Melville. In the BTR we see the signal to noise ratio (SNR) (from 10-40 dB) plotted as a function of time over the 3 hour closing run. The true bearing of the source is shown in the faint black line. At large distances a grazing bottom bounce is detected, with the conical beam being slightly nearer to endfire than the true bearing. As the range closes, the spread in the beam arrival grows to the point where energy is arriving on the array spread over up to 70 degrees in conical beam space. This is energy only reaching the array from a bottom bounce and there is significant evidence that it is out-of-plane scattering. (In plane scattering my be present as well, but it cannot explain the 70 degree spread when the true source is at broadside. As the range gets within 10 km, the direct path ray (and surface bounce) appears strongly and the conical beam and true source bearing overlap. This measurement of out-of-plane scattering is being used to drive the development of high-fidelity out-of-plane rough interface scattering propagation codes.

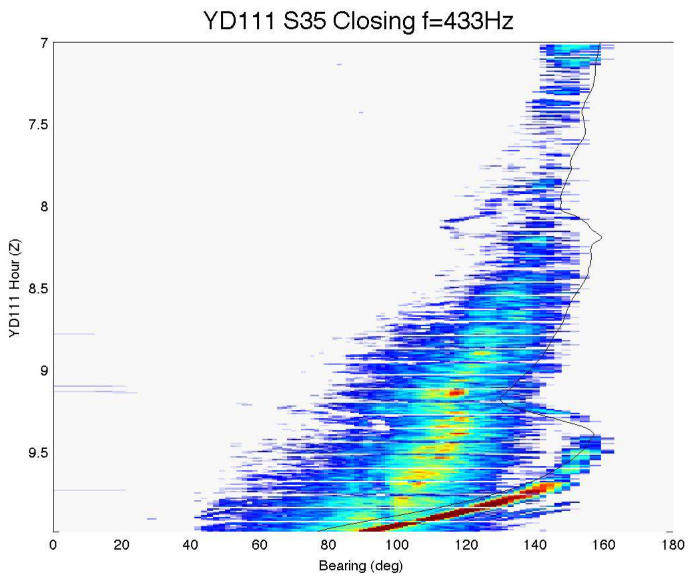

Figure 4. PhilSea09 Narrowband (433Hz) Bearing Time Record of the S35 closing processed from the Five Octave Research Aray.

During JD 113 of PhilSea09, the R/V Melville, under the direction of chief Scientist Dr. Gerald D'Spain (SIO), towed a ship suspended source towards the DVLA location. A set of narrowband tones was transmitted. The deep VLA data was processed into snapshots across the array. Conventional and adaptive Matched Field Processing (MFP) were applied using a range-independent environment with a geo-acoustic inversion developed through discussions with Dr. Ralph Stephen (WHOI). A single snapshot of the conventional and adaptive (Minimum Variance Distortionless Response – MVDR) beamformer are shown in Fig 5 for a single set of snapshots (covariance integration time = 20 x 1 s FFTs). The true source location is a range of 25.8 km and a depth of 50m. The conventional processor identifies a significant peak at the source depth, but the localization is broad in range and depth, as well as having sidelobes at more distant convergence zones. The MVDR (which is not normalized)

successfully filters out the sidelobes and generates a localization within 0.5 km in range and 10 m in depth. The capabilities of MFP for VLA source localization is significant focus of our FY11 work.

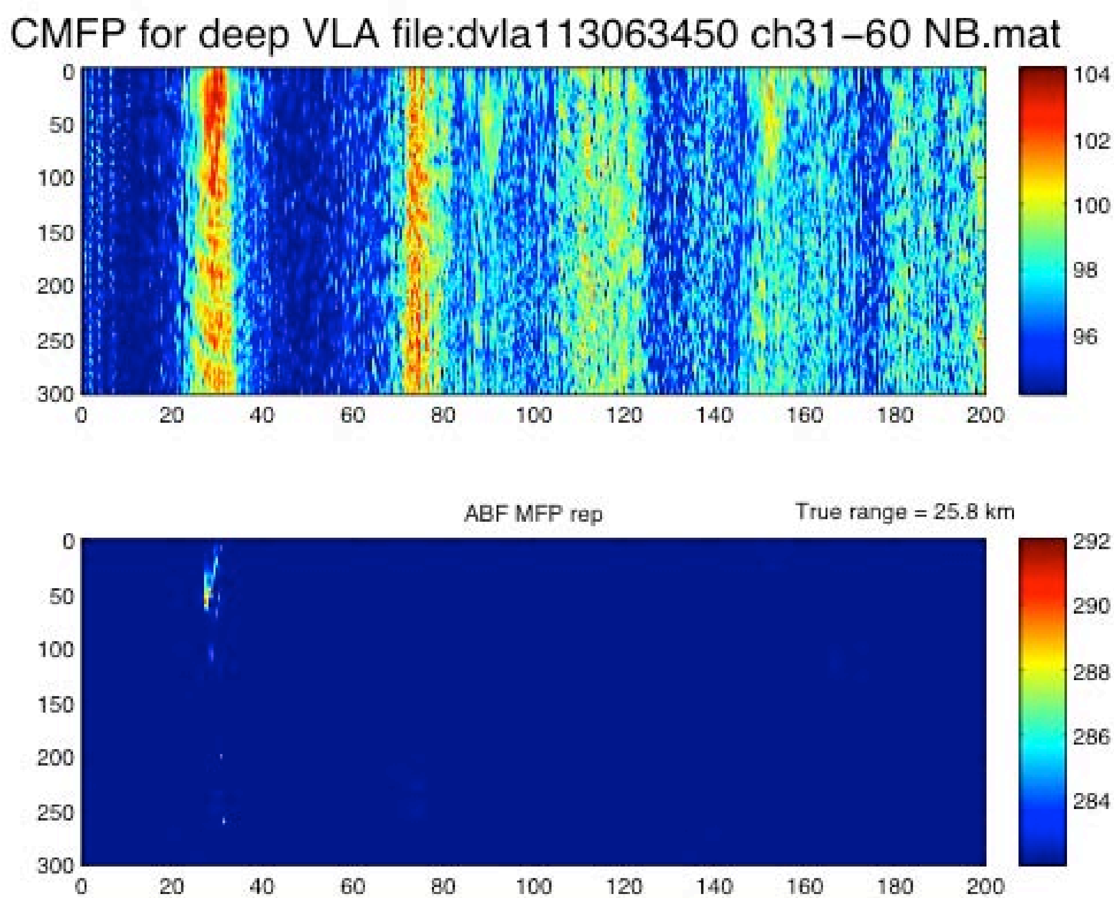

Figure 5. MFP ambiguity surfaces (range in km, depth in m) for Conventional (upper) and MVDR (lower) response for when R/V Melville was closing on the DVLA.

IMPACT/APPLICATIONS

This research is expected to impact deep ocean naval acoustics in 3 areas. The development of an integrated Nx2D parabolic equation, parses the sonar performance problem (as computed by Tactical Decision Aides) in a method more amenable to enhance efficiency using modern multi-threading computers. Development of an understanding of bottom roughness, particularly in deep water, will impact reverberation modeling and active ASW. The success of MFP at either quiet target detection, or long range localization has yet to be proven. Demonstration of these capabilities in deep water could impact future Navy systems.

TRANSITIONS

Although no specific transition paths have yet been identified for this work, the scientific findings can be incorporated in current deep-water passive detection approaches (via IWS5, APB). The

CRAM_Nx2D code has been briefed to OAML and talks are underway with the Naval Research Lab-Stennis Space Center to incorporate various aspects of it into NSPE.

RELATED PROJECTS

This project is related to the ONR RAP program, with emphasis on the structure of deep-water ambient noise and on the stability of bottom bounces propagation. The computational modeling code has been used extensively in the ONR PLUS-INP program and in the DARPA Non-Traditional Active Sonar program.

REFERENCES and PUBLICATIONS

1. M. Collins, Journal of the Acoustical Society of America **93** (4), 1736-1742 (1993).
2. K. D. Heaney, W. A. Kuperman and B. E. McDonald, Journal of the Acoustical Society of America **90** (5), 2586-2594 (1991).